Trend of R&D publications in Pressurised Heavy Water Reactors: A Study using INIS and Other Databases

Vijai Kumar, V. L. Kalyane, E. R. Prakasan, Anil Kumar, Anil Sagar, Lalit Mohan

Scientific Information Resource Division, Knowledge Management Group, Bhabha Atomic Research Centre, Trombay, Mumbai – 400 085, India e-mail: vijai@magnum.barc.ernet.in

Abstract. Digital databases INIS (1970-2002), INSPEC (1969-2002), Chemical Abstracts (1977-2002), ISMEC (1973-June2002), Web of Sciences (1974-2002), and Science Citation Index (1982-2002), were used for comprehensive retrieval of bibliographic details of research publications on Pressurized Heavy Water Reactor (PHWR) research. Among the countries contributing to PHWR research, India (having 1737 papers) is the forerunner followed by Canada (1492), Romania (508) and Argentina (334). Collaboration of Canadian researchers with researchers of other countries resulted in 75 publications. Among the most productive researchers in this field, the first 15 are from India. Top three contributors to PHWR publications with their respective authorship credits are: H.S. Kushwaha (106), Anil Kakodkar (100) and V. Venkat Raj (76). Prominent interdomainary interactions in PHWR subfields are: Specific nuclear reactors and associated plants with General studies of nuclear reactors (481), followed by Environmental sciences (185), and Materials science (154). Number of publications dealing with Geosciences aspect of environmental sciences are 141. Romania, Argentina, India and Republic of Korea have used mostly (≥75%) non-conventional media for publications. Out of the 4851 publications, 1228 have been published in 292 distinct journals. Top most journals publishing PHWR papers are: *Radiation Protection and Environment* (continued from: *Bulletin of Radiation Protection* since 1997), India (115); *Nuclear Engineering International*, UK (84); and *Transactions of the American Nuclear Society*, USA (68).

1. Introduction

The concept of heavy water reactors was introduced in 1944 and the first heavy water power reactor became critical on 11 April 1962 in Canada. The Canadians were the pioneers in the transition from research reactor to power reactor using heavy water. Subsequent research and development in Pressurized Heavy Water Reactors (PHWR) resulted in significant improvements in their design, efficiency and operation. Their cumulative benefits are quite substantial in many aspects; most important among them is utilization of uranium resources [1-5]. The study of publication output in a field is a good indicator of status of research work in that field. Bibliographic databases are representative samples of publication activity in any field of knowledge. This paper reports the findings of a study based on some databases where bibliographic details of PHWR publications are likely to occur. The results of this study could be beneficial to PHWR researchers in understanding the progress in this field and making them aware of the research status for appreciation and possible decision-making.

2. Materials and Methods

Keywords PHWR, and Pressurised or Pressurized Heavy Water Reactor were used for searches in title or descriptors. The searches resulted in a total of 5863 records. Taking INIS as base the duplicate records (1012) from INIS and other databases were identified and removed. Remaining 4851 records (Table I) were considered for the further study. A manual examination of Abstracts of each randomly selected 500 records among 4851 records showed that about three per cent records were not directly related to PHWR research but were only remotely related in passing remarks. The discussion and conclusions of this paper may be viewed in this light. It may be noted that, in general, results and conclusions of this paper will not be drastically affected due to the above observation. However, to ensure credibility of conclusions, the records pertaining to specific results were scrutinized for records directly related to PHWR results.

Table I: Databasewise PHWR related records

Database	PHWR records
INIS (1970 - 2002)	4655
INSPEC (1969 - 2002)	117
Chemical Abstracts (1977 - 2002)	63
ISMEC (1973 - June 2002)	9
Web of Sciences (1974 - 2002)	5
Science Citation Index (1982 - 2002)	2
Total	4851

For the data analysis of bibliographic records some programs written in Visual C++ language and SQL were employed. International Nuclear Information System (INIS) classification scheme [6-7] was followed to quantify domainary and inter-domainary content-wise global publications.

3. Results and Discussion

3.1. Growth of publications

The most famous 'Ideal Logistic Growth Model' of literature in a field has been well discussed in early 1990s [8-10]. Logistic growth assumes that the growth rate is proportional to the product of present size and future growth. The escalating growth after maturation implies that old topics of research are no longer relevant and new directions in research, new discoveries, and new opportunities keep growing. According to Gompertz the logistic growth of any field of knowledge ideally takes an extended S-shape [11]. Fig. 1 depicts year-wise and cumulative number of R&D publications related to PHWR since 1966.

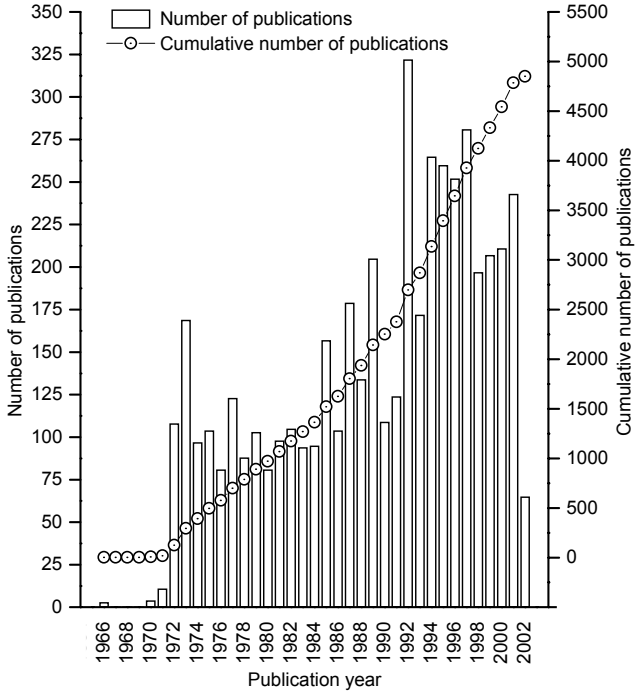

FIG. 1. PHWR related R&D publications

3.2. Country-Productivity and Collaboration

Even though PHWR type reactors are not common to all countries, nevertheless 46 countries have contributed to PHWR research. Country-wise publications productivity is given in Table II.

Table II. Productivity-wise list of countries contributing to the PHWR related research (1966-2002)

Country	Number of publications and country-wise affiliations										Total	%
	Single country	International collaborations										
		Two Countries		Three Countries			Four Countries					
		I	II	I	II	III	I	II	III	IV		
India	1724	7	4		1		1				1737	34.84
Canada	1417	39	29	4	2	1					1492	29.92
Romania	482	11	10	2		3					508	10.19
Argentina	320	5	6	1	2						334	6.70
Republic of Korea	201	10	6			1			1		219	4.39
Germany	164	8	16	1							189	3.79
USA	97	9	16	1	1	1					125	2.51
UK	67	1	2								70	1.40
Pakistan	54	3	2	1							60	1.20
Austria	36	3	2		4	3					48	0.96
USSR	27										27	0.54
Japan	13	1	1	2	1					1	19	0.38
Sweden	19										19	0.38
Italy	14	1			1	2					18	0.36
Egypt	11		1								12	0.24
France	8	1	1		1						11	0.22
Australia	8			1							9	0.18
Saudi Arabia	7	1									8	0.16
Brazil	5	1	1								7	0.14
Israel	7										7	0.14
China	3	2						1			6	0.12
Czechoslovakia	6										6	0.12
Yugoslavia	6										6	0.12
Indonesia	5										5	0.10
Spain	5										5	0.10
Turkey	5										5	0.10
South Africa	3		1								4	0.08
Sweden	1	1	1			1					4	0.08
Hungry		1	2								3	0.06
Switzerland		1	2								3	0.06
Finland	2										2	0.04
Mexico	2										2	0.04
Netherlands	1		1								2	0.04
Taiwan	2										2	0.04
Belgium	1										1	0.02
Denmark	1										1	0.02
Iraq	1										1	0.02
Latvia						1					1	0.02
Norway	1										1	0.02
Peru			1								1	0.02
Philippines	1										1	0.02
Poland	1										1	0.02
Republic of Moldova	1										1	0.02
Slovakia	1										1	0.02
Tunisia			1								1	0.02
Ukraine	1										1	0.02

(I = First author(s) country, II = Second author(s) country,
III = Third author(s) country, and IV = Fourth author(s) country)

India is at the top position followed by Canada, Romania, and Argentina. With respect to international collaborations, Canada is at the top with 75 publications, followed by USA (28), Romania (26), Germany (25), and Republic of Korea (18).

As per Katz and Hicks [12], collaborative papers have more impact than non-collaborative papers. Total number of internationally co-authored scientific and technical articles in ISI databases [13] had increased by 115% in ten years from 1986. Table II also gives the international collaboration pattern of the PHWR research. Out of 4851 publications, 106 (2.19 %) are of bilateral collaborative nature. Also there are thirteen publications with a collaboration of three countries, and one publication with a collaboration of four countries.

The total literature output on PHWR related research from top 6 countries amounted to about 90 per cent. Growth of publications by top ten highly productive countries is given in Fig. 2. Stepping in of Romania and Republic of Korea after 1992 in PHWR research is remarkable. The Fig. 2 also shows that India has overtaken Canada in year 2000 in publication activities.

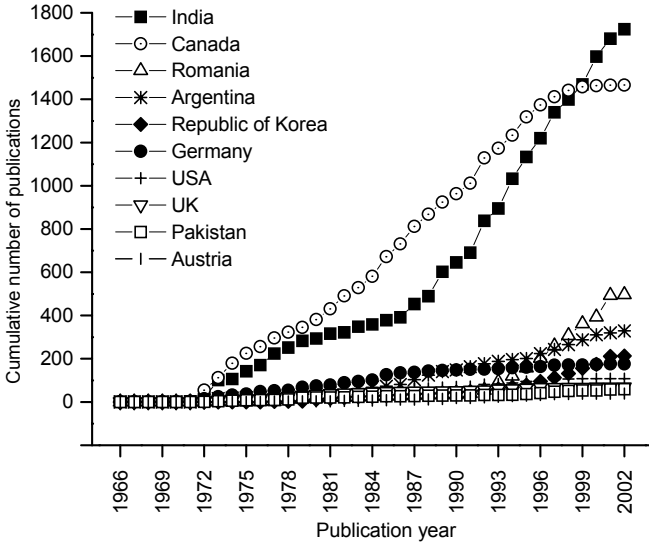

FIG. 2. Year-wise cumulative number of publications by top 10 countries in PHWR related research

3.3. Author-wise Productivity

Individual contribution to any field of science indicates the individual's expertise in that field. The PHWR records from all the databases show that, 5837 distinct authors have contributed to this field of study. The rank-wise list of the number of papers of first 52 authors (those who have at least 15 authorships credits) is given in Table III. Out of 111 top most authors 83 are Indians with 17 of them occupying the first 14 rank positions, and three authors have more than 75 authorships each to their credit. The productivity history of the top five authors in the PHWR related research is given in Fig. 3.

Table III. Most productive authors (those who have ≥ 15 publications to their credit) in the field of PHWR related research (1966-2002)

Sr.	Author	Affiliation	Authorships	Rank
1.	Kushwaha-HS	India	106	1
2.	Kakodkar-Anil	India	100	2
3.	Venkat-Raj-V	India	76	3
4.	Narasimhan-SV	India	48	4
5.	Mahajan-SC	India	44	5
6.	Mathur-PK	India	39	6
7.	Dutta-BK	India	37	7
8.	Das-M	India	36	8
9.	Raj-Baldev	India	29	9
10.	Ganguly-C	India	28	10
11.	Gurg-RP	India	25	11
12.	Mehta-SK	India	24	12
13.	Ghosh-AK	India	24	12
14.	Bajaj-SS	India	24	12
15.	Nair-KVK	India	24	12
16.	Gupta-SK	India	23	13
17.	Velmurugan-S	India	22	14
18.	Rotaru-I	Romania	21	15
19.	Vijayan-PK	India	20	16
20.	Purandare-HD	India	20	16
21.	Varadhan-RS	India	20	16
22.	Venkateswarlu-KS	India	20	16
23.	Srivenkatesan-R	India	19	17
24.	Bhardwaj-SA	India	19	17
25.	Chudalayandi-K	India	19	17
26.	Singh-RK	India	19	17
27.	Rustagi-RS	India	18	18
28.	Rastogi-BP	India	18	18
29.	Suk-HC	Rep. of Korea	18	18
30.	Krishnani-PD	India	18	18
31.	Srinivasan-KR	India	18	18
32.	Glodeanu-F	Romania	18	18
33.	Murthy-LGK	India	17	19
34.	Soni-RS	India	17	19
35.	Babar-AK	India	17	19
36.	Govindarajan-G	India	17	19
37.	Sinha-RK	India	17	19
38.	Venkateswaran-G	India	17	19
39.	Frischengruber-K	Argentina	16	20
40.	Jagannathan-V	India	16	20
41.	Purushotham-DSC	India	16	20
42.	Sharma-VK	India	16	20
43.	Galeriu-D	Romania	16	20
44.	Woodhead-LW	Canada	15	21
45.	Balakrishnan-K	India	15	21
46.	Chawla-DS	India	15	21
47.	Bapat-CN	India	15	21
48.	Iyengar-MAR	India	15	21
49.	Kumar-AN	India	15	21
50.	Markandeya-SG	India	15	21
51.	Ramamirtham-B	India	15	21
52.	Chirica-T	Romania	15	21

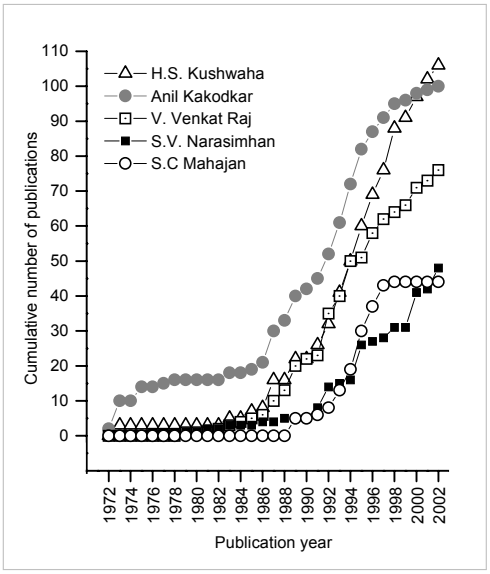

FIG. 3. Year-wise cumulative publications of top five authors in PHWR related research

3.4. Content Analysis

Table IV shows the cluster analysis of top 18 subject categories in the field of PHWRs. Number of records prominently occurring with S21: specific nuclear reactors and associated plants were:

- S22: general studies of nuclear reactors (481);
- S54: environmental sciences (185);
- S36: materials science (154);
- S29: energy planning, policy and economy (133);
- S42: engineering (120);
- S61: radiation protection and dosimetry (112); and
- S58: geosciences (98).

Table IV. Clusters of PHWR papers (1966-2002) as per INIS classification

Subject	S21	S22	S54	S29	S42	S36	S99	S61	S11	S58	S12	S37	S07	S46	S98	S63	S20	S38
S21	***3827***	481	185	133	120	154	92	112	68	98	39	16	23	16	9	36	17	3
S22		***722***	24	13	25	22	21	10	10	12	1	5	0	6	0	1	16	0
S54			***354***	9	7	4	3	17	4	141	15	2	1	5	0	4	0	0
S29				***261***	0	0	7	4	17	4	2	0	2	0	2	0	1	0
S42					***244***	13	4	1	5	4	11	2	1	2	5	0	0	0
S36						***213***	0	1	4	3	4	3	0	0	0	0	0	0
S99							***202***	7	2	1	0	0	1	0	1	0	0	1
S61								***194***	0	2	1	2	0	2	1	1	1	1
S11									***158***	3	13	2	2	0	4	0	0	1
S58										***146***	9	1	0	0	0	2	0	0
S12											***139***	0	2	1	2	0	0	3
S37												***54***	6	2	1	1	0	0
S07													***53***	3	0	0	0	2
S46														***51***	1	0	0	1
S98															***34***	0	0	0
S63																***21***	0	0
S20																	***18***	0
S38																		***13***

INIS Subject Categories

S07 Isotopes and radiation sources
S11 Nuclear fuel cycle and fuel materials
S12 Management of radioactive wastes, and non-radioactive wastes from nuclear facilities
S20 Fossil-fueled power plants
S21 Specific nuclear reactors and associated plants
S22 General studies of nuclear reactors
S29 Energy planning, policy and economy
S36 Materials science
S37 Inorganic, organic, physical and analytical chemistry
S38 Radiation chemistry, radiochemistry and nuclear chemistry
S42 Engineering
S46 Instrumentation related to nuclear science and technology
S54 Environmental sciences
S58 Geosciences
S61 Radiation protection and dosimetry
S63 Radiation, thermal, and other environmental pollutant effects on living organisms and biological materials
S98 Nuclear disarmament, safeguards and physical protection
S99 General and miscellaneous

Interdomainary contents of S54: environmental sciences with S58: geosciences is in 141 publications followed by:

- S21: specific nuclear reactors and associated plants with S12: management of radioactive wastes, and non-radioactive wastes from nuclear facilities (39);
- S21: specific nuclear reactors and associated plants with S63: radiation, thermal, and other environmental pollutant effects on living organisms and biological materials (36);
- S22: general studies of nuclear reactors with S42: engineering (25); and
- S22: general studies of nuclear reactors with S54: environmental sciences (24).

3.5. Types of Publication Media

INIS: guide to bibliographic description [14] was used to group the records according to their publication media. Out of the 4851 publications, 3005 (61.95%) were published as conference/symposium papers, 1228 (25.31%) were journal articles, 555 (11.44%) were technical reports and 63 (1.30%) were other publication media like books, theses, dissertations, patents, films, etc. Comparison of growth in literature of PHWR related research in terms of their publication media are given in Fig. 4. The number of conferences/symposia/seminars, etc. held with power reactors especially PHWR type reactors as the theme, was high during this period.

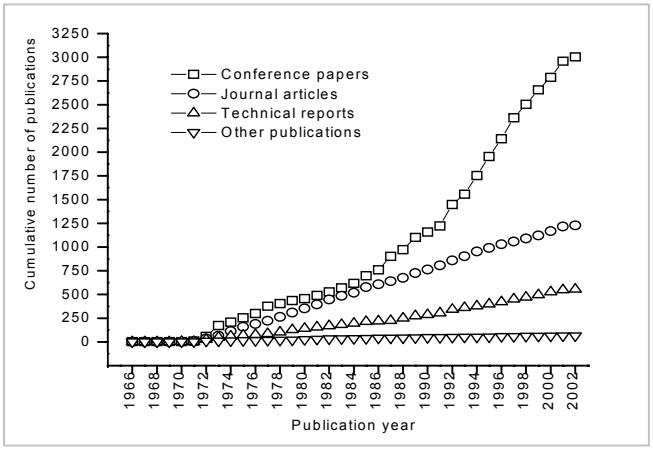

FIG. 4. Publication media–wise cumulative number of publications of PHWR related research

Observation to the growth pattern indicates that the period from 1990 to 1993 was a landmark in PHWR research. Publication media-wise highly productive mode years were: conference papers (1992) and journal articles (1985), technical reports (1992) and other publications clubbed (1972). It is interesting to note the high percentage of Non-Conventional Literature (NCL) which includes technical reports; conference/symposia/seminar papers; theses; dissertations, etc. The percentages of NCL for the top ten countries mentioned above are Romania (84.50 %); Argentina (81.71 %); India (78.42 %); Korea, Republic of (72.07 %); Austria (68.00 %); Canada (67.49 %); USA (63.49 %); Pakistan (59.70 %); Germany (47.12 %); and UK (18.31 %), etc. The high proportion of NCL may be due to urgency of communication to the targeted audience [15].

3.6. Journal-wise Productivity

For the past 2-3 decades scientometricians have focused their studies on journal articles since they form a major share of peer reviewed and quality scientific research output as compared to NCL

including technical reports, conference papers, monographs etc. In the present study, it is found that 292 distinct journals were used to publish 1228 publications (25.31%) out of a total of 4851 publications. Out of these journals, 171 were used prior to the year 1992. After 1992 most popular journals preferred were 80 only. However, 41 journals were common in both the periods. Table V documents journals (having at least 6 publications) preferred by PHWR researchers. By the year 2002, the journal *Radiation Protection and Environment* (continued from the journal *Bulletin of Radiation Protection* since 1997) contained the maximum number of publications on PHWR.

Table V. Journals preferred for publishing articles on PHWR related research (1966-2002)

Journal Title	Impact Factor (2001)	Country	No. of Papers	Papers/ Year
*Radiation Protection and Environment**	NA	India	115	4.79
Nuclear Engineering International	0.610	UK	84	3.36
Transactions of the American Nuclear Society	NA	USA	68	2.52
Nuclear Canada/Canada Nucleaire	NA	Canada	42	1.68
Modern Power and Engineering #	NA	Canada	39	3.25
Nuclear Engineering and Design	0.233	The Netherlands	38	1.23
Journal of the Korean Nuclear Society	NA	Republic of Korea	29	2.07
Energetica Seria A	NA	Romania	26	1.18
Nuclear Canada Yearbook	NA	Canada	25	1.47
Nuclear Technology	0.421	USA	25	1.14
Annals of Nuclear Energy UK	0.358	UK	22	0.92
Canadian Nuclear Society Bulletin	NA	Canada	21	1.62
Atomwirtschaft Atomtechnik Germany	NA	Germany	20	1.33
Journal of Nuclear Materials	1.366	The Netherlands	19	0.95
Ascent Canada	NA	Canada	17	1.31
Atomkernenergie Kerntechnik Germany	NA	Germany	17	2.43
Atomnaya Tekhnika za Rubezhom	NA	USSR	17	0.63
Canadian Energy News	NA	Canada	15	3.00
Atom und Strom	NA	Germany	14	1.00
Nucleus Karachi	NA	Pakistan	14	0.93
Canadian Chemical Processing	NA	Canada	10	0.83
Fusion Technology USA	0.582	USA	10	0.91
International Journal of Pressure Vessels and Piping	0.250	UK	10	0.53
3 journals with 9 papers each			27	
4 journals with 8 papers each			32	
4 journals with 7 papers each			28	
6 journals with 6 papers each			36	
10 journals with 5 papers each			50	
12 journals with 4 papers each			48	
17 journals with 3 papers each			51	
46 journals with 2 papers each			92	
167 journals with 1 paper each			167	
Total 292 journals			1228	

(NA = Not Available; * continued from: *Bulletin of Radiation Protection India* since 1997; # ceased publication from 1984)

Profiles of PHWR related publications in seven core journals namely *Radiation Protection and Environment*, *Nuclear Engineering International*, *Transactions of the American Nuclear Society*, *Nuclear Canada/Canada Nucleaire*, *Modern Power and Engineering Canada* (Ceased from 1984), *Nuclear Engineering and Design*, and *Journal of the Korean Nuclear Society* are presented in Fig. 5.

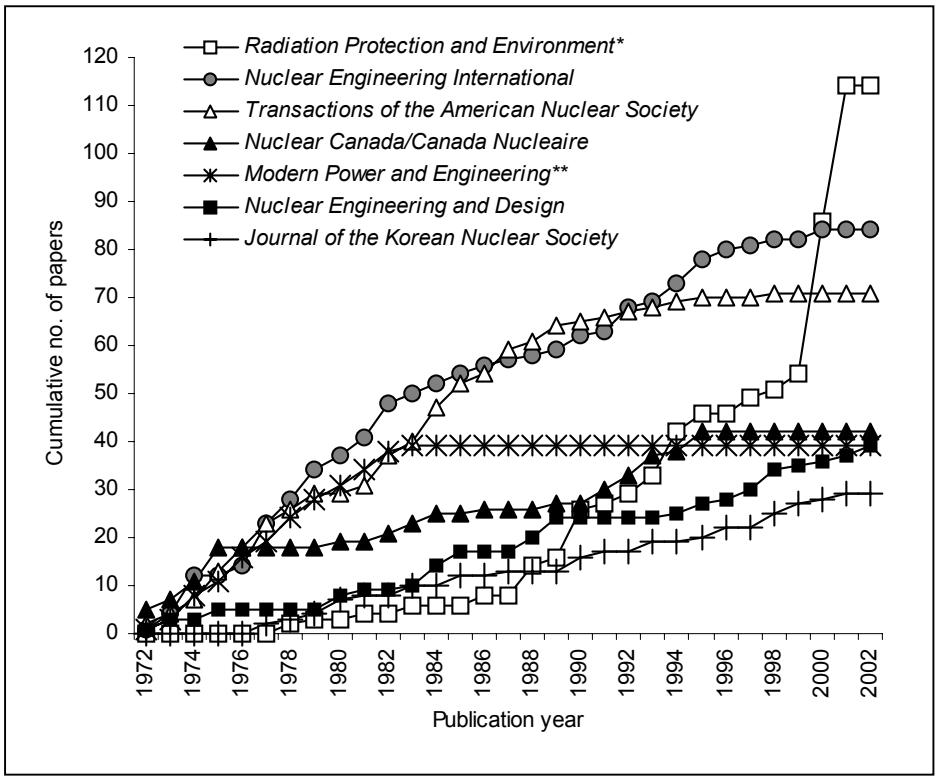

FIG. 5. Year-wise cumulative number of papers published in the core journals
(* Continued from *Bulletin of Radiation Protection* since 1997; ** Ceased from 1984)

4. Conclusions

Pressurized Heavy Water Reactor related R&D publications at global level during 1966-2002 were 4851. India has emerged as leader in PHWR followed by Canada, Romania, Argentina, and Republic of Korea. Expertise of H.S. Kushwaha, Anil Kakodkar, V. Venkat Raj, S.V. Narasimhan, and S.C. Mahajan in the area of PHWR is evident from the number of publications to their credits. The scientists working in the field have preferred to publish their research papers as conference/symposia papers followed by journal articles and technical reports. Highly used channels of communication were *Radiation Protection and Environment*, *Nuclear Engineering International*, *Transactions of the American Nuclear Society*, *Nuclear Canada/Canada Nucleaire*, *Modern Power and Engineering Canada* (Ceased from 1984), *Nuclear Engineering and Design*, and *Journal of the Korean Nuclear Society*.

5. Acknowledgements

The authors acknowledge the help rendered by Mr. Amardeep Vidyarthi of Computer Division, Mr. P.R. Kallolkar, Mr. Sanjay Kumar Singh, Mr. Sandeep Kadam and Mr. Sanu Mathew of Scientific Information Resource Division of BARC, Mumbai.

6. References

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Heavy-water reactors: bibliographical series no. 37. Vienna, IAEAIX-XIII (1970).

[2] BENNET, Lewis W., Advanced HWR power plants, Transactions of the American Nuclear Society **15** (1972) 1.

[3] WEST, J.M., ABBOTT, W.E., DIETRICH, J.R., Advanced HWR power plants. Transactions of the American Nuclear Society **15** (1972) 1-2.

[4] PON, G.A., Future steps in Canada's nuclear power programme. Energy International, **9** 9 (1972) 18-20.

[5] DEPARTMENT OF MECHANICAL ENGINEERING, INDIAN INSTITUTE OF TECHNOLOGY, Introduction to nuclear power engineering. Pt. 4. Heavy Water Reactors, Organic Moderated Reactors, Liquid-Metal Cooled Reactors. Mumbai, IIT (1974).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, INIS Circular Letter No. 161 (1999).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, INIS: subject categories and scope descriptions. Vienna, IAEA, (1997).

[8] BRAUN, Tibor, SCHUBERT, Andras P., KOSTOFF, Ronald N., Growth and trends of fullerene research as reflected in its journal literature. Chemical Reviews, **100** 1 (2000) 23-37.

[9] GARG, K.C., PADHI, P., Scientometrics of laser research in India during 1970-1994. Scientometrics, **55** 2 (2002) 215-241.

[10] GARG, K.C., KARI, M.M.S., Bibliometrics of research communication of INSA fellows, Journal of Scientific & Industrial Research, **51** (1992) 929-935.

[11] SHARMA, Praveen, GUPTA, B.M., SURESH KUMAR, Application of growth models to science and technology literature in research specialties. DESIDOC Bulletin of Information Technology, **22** 2 (2002) 17-25.

[12] SYLVAN KATZ, J., HICKS, Diana, How much is collaboration worth? A calibrated bibliometric model. Proceedings on the sixth conference of The International Society for Scientometric and Informetric, Jerusalem, Israel, June 16-19 (1997) 163-175.

[13] ARUNACHALAM, Subbiah, JINANDRA DOSS, M., Mapping international collaboration in science in Asia through coauthorship analysis. Current Science (India), **79** 5 (2000) 621-628.

[14] BARREIRO, Selma Chi, HARDIN, Nancy E. (Eds.), INIS: Guide to bibliographic description (IAEA-INIS-1 Rev.8). Vienna, IAEA (1992).

[15] SWARNA, T., KALYANE, V.L., VIJAI KUMAR, Scientometric dimensions of technical reports from Bhabha Atomic Research Centre. Malaysian Journal of Library and Information Science, **7** 1 (2002) 17-30. http://eprints.rclis.org/archive/00001506/